Combined sewer networks for cities with hot and dry climates; a design optimization approach

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Highlights

- An optimization approach is introduced to design combined sewer networks.
- Sewer network layout and hydraulic specifications alongside the size, location, and operation of combined sewer overflow structures are optimized simultaneously.
- Combined sewer networks are well-suited to hot and dry climates, specifically for low-budget and crowded cities.

Introduction

If the same sewer network collects both sanitary sewage and stormwater flows, it is called Combined Sewer Network (CSN). The most challenging problem of CSNs is their Combined Sewer Overflows (CSOs) into local streams during periods of heavy rainfalls. CSOs contain untreated human and industrial waste, toxic materials, and debris and could severely threaten the environment and public health. Hence, designing a new CSN has been almost obsoleted and prohibited for decades. Currently, nearly all clean water regulations and standards worldwide have put pressure on communities with CSN to apply CSO control strategies and preferably construct separate networks. However, high costs and physical restrictions are significant barriers to building separate stormwater management systems, particularly in old and crowded cities. Therefore, striking academic and engineering efforts have been put into CSOs reduction strategies, e.g., optimum operation of CSO structures (Bachmann-Machnik et al. 2021), green technologies (Lund et al. 2019), and real-time control strategies (Wei et al. 2021). Despite earlier reasoning, studies on river water quality strongly indicate that the separate system is not always a preferable solution because the polluted runoff from streets, containing, e.g., different heavy metals, is discharged directly into the river (Toffol et al. 2007). If the runoff contains significant pollutions, a CSN might release fewer pollutions in the environment over a year than a separate system. The reason is that small rain events with high concentrations would be treated at the WWTP while during heavy rainfall events, for the CSOs, there is a substantial dilution already (Toffol et al. 2007).

The literature reveals that investigations into CSNs problems have been mainly concentrated on European communities, obviously because of high precipitation, existing old CSNs, and ever-increasing attention to environmental protection. The European standards and regulations on urban water management are very strict with the CSOs. They are oftentimes translated into other languages and respected in different countries worldwide. However, although the goals of urban water management (wastewater and runoff collection, treatment, disposal, and reusing) are the same worldwide, the local climates, physical constraints, financial restrictions, and social and environmental considerations are different. There are certain regions located in dry and hot climates suffering from prolonged and severe droughts. Examples are most parts of the Middle East and north of Africa. In these regions with low perceptions and rare heavy rainfalls per year, the design and operation of two separated sewer systems are technically and economically inappropriate. In addition, some physical restrictions, specifically in highly urbanized, crowded, and old cities may make separate systems practically impossible. Under these conditions, the design of CSNs may have the potential for wastewater management if they are optimally designed and operated in terms of CSOs reduction. After all, the city's climate, financial and physical conditions largely impact the feasibility of combined sewer systems, its CSN should be designed carefully to ensure CSO structures' optimum sizing, allocation, and operation. Thus, this research aims at dealing with the importance of CSNs optimization, and to reveal if CSNs could be favorable under specific conditions.

Methodology

A mathematical programming problem is defined and solved using a Tabu Search metaheuristic method to design a CSN with minimum construction cost and CSO objectives while satisfying all technical and physical constraints (Bakhshipour et al. 2019). The proposed optimization framework is depicted in Fig. 1.

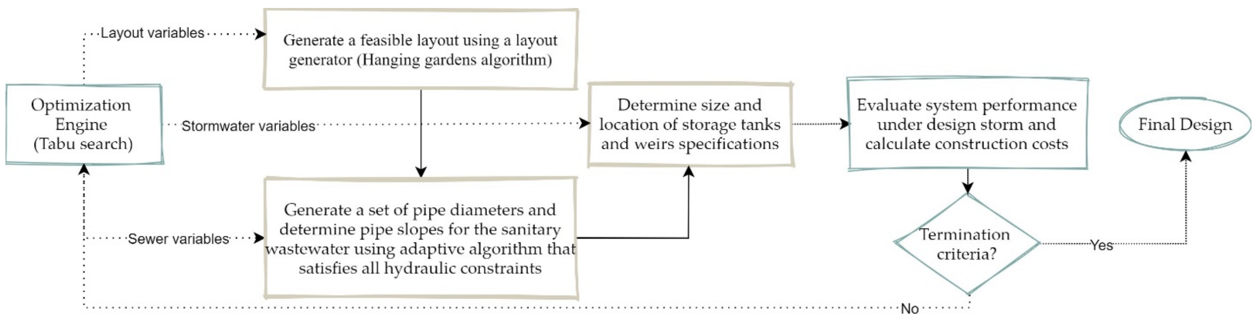

Figure 1. The proposed optimization framework

The case study is a 500-ha part of a large industrial city, Ahvaz, in the southwest of Iran. It has a semi-dessert climate, and flat topography, in the proximity of a large river (with an average flow of 500 m^3/s). The city is currently not having a stormwater management system. Relatively intense rainfalls cause severe urban floods, resulting in public, economic, and environmental challenges two or three times per year. Due to the aforementioned issues and the unaffordable high initial investment costs, it is not feasible for the city to construct two separate wastewater and stormwater collection systems. The average number of rainy days in Ahvaz is 24 days, and the average annual precipitation is 210 mm. The design criteria for dry weather conditions (sanitary system) include minimum and maximum flow velocities, minimum pipe slope, maximum excavation depths, and proportional water depths. Based on the WWTP capacity, the maximum outflow at the outlet in wet weather conditions is limited to 1.4 m^3/s. Only storage tanks near the river are allowed to overflow. Construction costs of pipes, manholes and storage tanks are used as the optimization cost function.

Results and discussion

Once the design and optimization of the network for the 5-year storm are implemented, the network configuration is obtained, as illustrated in Fig. 2. We also evaluated the system performance under other extreme events, including a recorded rainfall time series between October 2018 to March 2019, as presented in Table 1. This period was selected because of several extreme events that caused severe flood damage in the area. Total precipitation during this period was 268 mm. As seen, even during the 25-year storm, less than 50% of the CSO is discharged into the river, and the rest remains in the network storage while gradually conducted to the WWTP and treated. Urban flooding only occurs during the 25 years storm. The overflow volume to wet weather volume is only about 18.7% for the recorded precipitation. It is worth mentioning that for the 2-year design storm, no CSO occurs in the system. The optimal design includes 14 storage tanks with a capacity ranging from 1000 to 5500 m3. The maximum pipe diameter for this design is 2.2 m.

Conclusions and future work

- The results indicate that combined sewer systems are still promising for wastewater management in hot and dry climates, specifically in old and crowded cities with financial and physical obstacles to building separate urban drainage systems.
- Simulations and implicit optimization of all components of a CSN would result in a cost-effective design and an environmentally friendly operation.
- CSNs can still be helpful in certain environmental aspects if they are optimized well to lessen the burden of CSOs and increase the rate of combined sewer flows treatment.

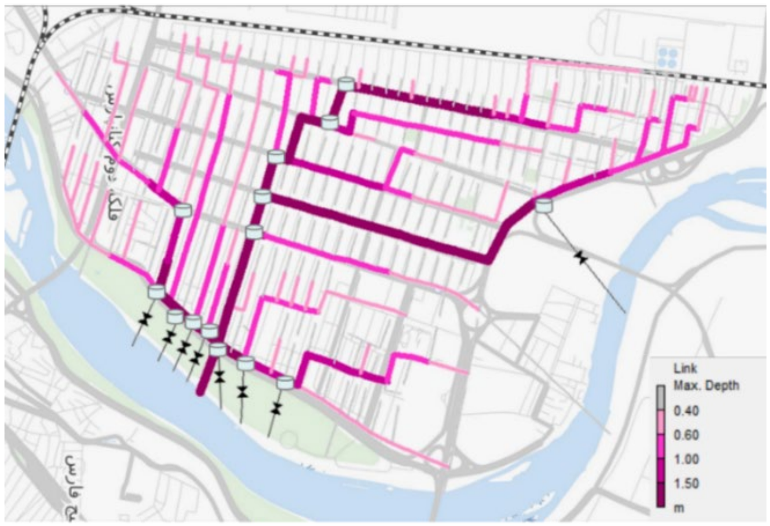

Figure 2. Optimal design (construction costs = 29.6 million $ or 395$/length pipe)

Table 1. Comparing the performance of the optimal design under different rain events

Storm	Avg. max pipes flow (LPS)	Avg. max pipes velocity (m/s)	Avg. max/full pipes depth	Avg. storages depth (%)	Avg. max storages depth (%)	Flooding (m3)	Sum of Overflow (m3)	Overflow/Wet Weather (%)
2 Years	388	0.93	44%	24%	43%	0	0	0.0%
5 Years	533	1.03	64%	37%	67%	0	44724	37.5%
25 Years	792	1.29	95%	42%	82%	11248	80606	48.6%
Timeseries	430	0.95	57%	11%	69%	0	196136	18.7%

This research studied the suitability of CNSs for dry and hot climates, and pointed out the potential of optimization models to improve their design and operation. Future works include other aspects of CSNs like structural decentralization, green-blue infrastructures, real-time control, deriving operating rule curves for CSOs, probabilistic modeling, uncertainty analysis, and multiobjective optimization considering other performance criteria like resilience and water quality.

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